A METHOD OF FORMING STEPPED STRUCTURES EMPLOYING IMPRINT LITHOGRAPHY

BACKGROUND OF THE INVENTION

[0001] The field of invention relates generally to micro-fabrication of structures. More particularly, the present invention is directed to forming patterned substrates suitable for use in damascene processes.

[0002] Micro-fabrication involves the fabrication of very small structures, e.g., having features on the order of micro-meters or smaller. One area in which micro-fabrication has had a sizeable impact is in the processing of integrated circuits. As the semiconductor processing industry continues to strive for larger production yields while increasing the circuits per unit area formed on a substrate, micro-fabrication becomes increasingly important. Micro-fabrication provides greater process control, while allowing increased reduction of the minimum feature dimension of the structures formed.

[0003] A common process employed during the manufacturing of integrated circuits involves fabrication of metal conductive lines and contacts. The contacts interconnect adjacent conductive lines separated by an insulative layer. Conductive lines and contacts are often fabricated by forming a stepped structure in a substrate, referred to as a via and a trench. A common means by which to form the via-trench stepped structure is known as the damascene process.

[0004] Damascene involves forming grooves in an insulating layer and filling the same with a conductive material, such as aluminum, copper and the like. In this manner, conductive lines are formed in the groove. To

form the contacts, as well as the conductive lines, a dual damascene process is typically employed to form a via in the region of the insulating layer in which the groove is formed.

[0005] An exemplary dual damascene process patterns on the insulating layer an image pattern of a via. To that end, the insulating layer is coated with a photo-resist and exposed through an appropriate mask which is then exposed to form the image pattern of the vias. The pattern is anisotropically etched in the upper portion of the insulating layer. The photo-resist is then exposed through a second mask with an image pattern of the grooves after being aligned with the first mask pattern to encompass the vias. Anisotropically etching the grooves for the conductive lines in the upper portion of the insulating material results in the via, already present in the upper portion of the insulating layer, to be simultaneously etched and replicated in the lower portion of the insulating material. After the etching is complete, both the vias and the grooves are filled with a conductive material metal. Simultaneously filling both the grooves and the vias with conductive material is an improvement over the single damascene process. However, the dual damascene process is attendant with disadvantages such as requiring alignment between two different masks. In addition, to increase process time and cost required by two mask steps, alignment becomes critical to properly position the groove with respect to the via.

[0006] There is a need, therefore, to provide improved processes for forming stepped structures in furtherance of the fabrication of integrated circuits.

SUMMARY OF THE INVENTION

[0007] The present invention provides a method for forming a stepped structure on a substrate and features transferring, into the substrate, an inverse shape of a multi-tiered structure. In one embodiment, the multi-tiered structure includes a bi-level protrusion having a projection and shoulders. The projection has an apex surface, and the shoulders are spaced-apart from the apex surface and the substrate, defining the shape. An exemplary use for the present invention is the formation of a self-aligned trench-via structure. To that end, the dimensions of the via portion are established as a function of the dimensions of the projection. The dimensions of the trench portion are established as a function of the dimensions of the shoulders. In another embodiment, the multi-tiered structure is an island formed on the substrate. These and other embodiments are described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Fig. 1 is a perspective view of a lithographic system in accordance with the present invention;

[0009] Fig. 2 is a simplified elevation view of a lithographic system, shown in Fig. 1, employed to create a patterned imprinting layer in accordance with the present invention;

[0010] Fig. 3 is a simplified representation of material from which a patterned imprinting layer, shown in Fig. 2, is comprised before being polymerized and cross-linked in accordance with the present invention;

[0011] Fig. 4 is a simplified representation of cross-linked polymer material into which the material, shown in Fig. 3, is transformed after being subjected to radiation in accordance with the present invention;

[0012] Fig. 5 is a simplified cross-sectional view of an imprint device spaced-apart from the patterned imprinting layer, shown in Fig. 1, after patterning in accordance with the present invention;

[0013] Fig. 6 is a simplified cross-sectional view of the patterned imprinting layer, shown in Fig. 5, after formation of a multi-layered structure by deposition of an etch selectivity layer, adjacent thereto, in accordance with one embodiment of the present invention;

[0014] Fig. 7 is a simplified cross-sectional view after a blanket etch of the multi-layered structure, shown in Fig. 6, to form a crown surface in accordance with one embodiment of the present invention;

[0015] Fig. 8 is a simplified cross-sectional view of the multi-layered structure, shown in Fig. 7, after subjecting the crown surface to an etch to form via portions in the substrate in accordance with one embodiment of the present invention;

[0016] Fig. 9 is a simplified cross-sectional view of the multi-layered structure, shown in Fig. 8, after subjecting the crown surface to an anisotropic etch to form trench portions aligned with the via portions in accordance with one embodiment of the present invention;

[0017] Fig. 10 is a simplified cross-sectional view of the multi-layered structure, shown in Fig. 9, after deposition of conductive material in the via portion and trench portion in accordance with one embodiment of the present invention;

[0018] Fig. 11 is a simplified cross-sectional view after a blanket etch of the multi-layered structure, shown in Fig. 6, to form a crown surface in accordance with a first alternate embodiment of the present invention;

[0019] Fig. 12 is a simplified cross-sectional view of the multi-layered structure, shown in Fig. 11, after subjecting the crown surface to an anisotropic etch to form a first segment of a via portion in a substrate;

[0020] Fig. 13 is a simplified cross-sectional view of the multi-layered structure, shown in Fig. 12, after subjecting the crown surface to a blanket etch to expose regions of the patterned imprinting layer and to form a second segment of a via portion;

[0021] Fig. 14 is a simplified cross-sectional view of the multi-layered structure, shown in Fig. 13, subjecting the same to an anisotropic fluorine etch to form a trench portion and a third segment of a via portion;

[0022] Fig. 15 is a top down view of protrusions, shown in Fig. 5, in accordance with a second alternate embodiment of the present invention;

[0023] Fig. 16 is a top down view of protrusions, shown in Fig. 5, in accordance with a third alternate embodiment of the present invention;

[0024] Fig. 17 is a cross-sectional view of the protrusions shown in Fig. 5, in accordance with a fourth alternate embodiment of the present invention;

[0025] Fig. 18 is a top down view of protrusions, shown in Fig. 17, in accordance with a fifth alternate embodiment of the present invention;

[0026] Fig. 19 is a top down view of protrusions, shown in Fig. 17, in accordance with a sixth alternate embodiment of the present invention;

[0027] Fig. 20 is a view of a substrate having formed therein a recess that is an inverse shape of the protrusion shown in Fig. 17;

[0028] Fig. 21 is a cross-sectional view of a substrate having islands formed thereon, in accordance with a seventh alternate embodiment of the present invention;

[0029] Fig. 22 is a simplified cross-sectional view showing a mold and patterned layer having a shape complementary to the mold employed to form the protrusions shown in Fig. 21;

[0030] Fig. 23 is a cross-sectional view showing a crown surface formed after etching of an etch selectivity layer deposited on the patterned layer shown in Fig. 22;

[0031] Fig. 24 is a cross-sectional view of the multi-layered structure, shown in Fig. 23, after subjecting the crown surface to an etch to expose regions of the substrate; and

[0032] Fig. 25 is a simplified cross-sectional view of the substrate and the imprint device, shown in Fig. 5, in accordance with an eighth alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0033] Fig. 1 depicts a lithographic system 10 in accordance with one embodiment of the present invention that includes a pair of spaced-apart bridge supports 12 having a bridge 14 and a stage support 16 extending therebetween. Bridge 14 and stage support 16 are spaced-apart. Coupled to bridge 14 is an imprint head 18, which extends from bridge 14 toward stage support 16. Disposed upon stage support 16 to face imprint head 18 is a motion stage 20. Motion stage 20 is configured to move with respect to stage support 16 along X- and Y-axes. A radiation source 22 is coupled to system 10 to impinge actinic radiation upon motion stage 20. As shown,

radiation source 22 is coupled to bridge 14 and includes a power generator 23 connected to radiation source 22.

[0034] Referring to both Figs. 1 and 2, connected to imprint head 18 is a substrate 26 having a patterned mold 27 thereon. Patterned mold 27 includes a surface 27a having a pattern formed therein. The pattern is defined by a plurality of spaced-apart recesses 28 and protuberances 29. Recesses 28 have a stepped shape with a groove portion 29a flanked by stepped-portions 29b. The combined width, "W_C," of each recess 28 is a sum of a width "W_1" of groove portion 29a and $2W_2$, where W_2 is a width of one of stepped-portions 29b. Protuberances 29 have a width, "W_3". Each of widths, W_1, W_2 and W_3 are measured in a direction that extends transversely to the Z axis. The original pattern is to be transferred into a substrate 31 positioned on motion stage 20. Substrate 31 typically comprises of a wafer 31a made from a suitable material, such as silicon. Substrate 31 may also comprise of wafer 31a having one or more layers of material disposed thereon. In the present example, substrate 31 is shown as including multiple layers 31c and 31e of dielectric material, such as organosilicate glass (OSG), which has a composition of $Si_WC_XO_YH_Z$. Adjacent layers 31c and 31e of OSG may be separated by an etch barrier 31d made from any suitable material, such as titanium nitride (TiN). An additional etch barrier layer 31b may be positioned between dielectric layer 31c and wafer 31a.

[0035] Referring to both Figs. 2 and 3, a flowable region, such as a patterned imprinting layer 34, is disposed on a portion of surface 32 that presents a substantially smooth profile. Flowable region may be formed using any known technique, such as a hot embossing

process disclosed in United States patent number 5,772,905, which is incorporated by reference in its entirety herein, or a laser assisted direct imprinting (LADI) process of the type described by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, Nature, Col. 417, pp. 835-837, June 2002. In the present embodiment, however, a flowable region consists of patterned imprinting layer 34 being deposited as a plurality of spaced-apart discrete beads 36 of material 36a on substrate 31, discussed more fully below. Patterned imprinting layer 34 is formed from a substantially silicon-free material 36a that may be selectively polymerized and cross-linked to record the original pattern therein, defining a recorded pattern. Material 36a is shown in Fig. 4 as being cross-linked at points 36b, forming cross-linked polymer material 36c. An exemplary embodiment of material 36a is formed from a compound of approximately 48% by weight of a cyclohexyl acrylate, a monomer available from Polyscience Company, Niles, Illinois; approximately 48% by weight ethylene glycol diacrylate, a cross-linking agent available from Sigma-Aldrich Corporation of St. Louis, Missouri; and approximately 4% by weight of a free radical generator sold under the tradename Darocur® and available from Ciba of Tarrytown, New York.

[0036] Referring to Figs. 2, 3 and 5, the pattern recorded in patterned imprinting layer 34 is produced, in part, by mechanical contact with patterned mold 27. To that end, imprint head 18, shown in Fig. 1, is adapted to move along the Z-axis and to vary a distance "d" between patterned mold 27 and substrate 31. In this manner, patterned mold 27 spreads beads 36 so as to form patterned imprinting layer 34 with a contiguous formation

of material 36a over surface 32. Alternatively, or in conjunction with imprint head 18, motion stage 20 may move substrate 26 along the Z-axis to allow mechanical contact between beads 36 and patterned mold 27. In one embodiment, distance "d" is reduced to allow sub-portions 34c of patterned imprinting layer 34 to ingress into and to fill recesses 28. This facilitates the original pattern on patterned mold 27 to be imprinted into a flowable region of substrate 31.

[0037] To facilitate filling of recesses 28, material 36a is provided with the requisite properties to completely fill recesses 28, while covering surface 32 with a contiguous formation of material 36a. In the present embodiment, sub-portions 34c of patterned imprinting layer 34 in superimposition with protuberances 29 remain after the desired, usually minimum distance "d," has been reached, leaving a projection 34a with a thickness t_1, shoulders 34b with a thickness t_2 and sub-portions 34c with a thickness t_3. Projection 34a and shoulders 34b define a bi-level protrusion on surface 32 of substrate 31. Sub-portion 34c is referred to as a residual layer, and thickness t_3 is referred to as a residual thickness. Thicknesses "t_1", "t_2" and "t_3" may be any thickness desired, dependent upon the application.

[0038] Referring to Figs. 2, 3 and 4, after a desired distance "d" has been reached, radiation source 22 produces actinic radiation that polymerizes and cross-links material 36a, forming cross-linked polymer material 36c. As a result, the composition of patterned imprinting layer 34 transforms from material 36a to material 36c, which is a solid. Specifically, material 36c is solidified to provide side 34d of patterned imprinting layer 34 with a shape conforming to a shape of

a surface 27a of patterned mold 27, shown more clearly in Fig. 5. In this manner, a plurality of solidified bi-level protrusions 34e is formed on substrate 31. After patterned imprinting layer 34 is transformed to consist of material 36c, shown in Fig. 4, imprint head 18, shown in Fig. 1, is moved to increase distance "d" so that patterned mold 27 and patterned imprinting layer 34 are spaced-apart.

[0039] An inverse shape of bi-level protrusions 34e is transferred into substrate 31 to form a via portion (not shown) and a trench portion (not shown) therein. In this manner, the dimensions of the via portion (not shown) are established as a function of the dimensions of projections 34a, and the dimensions of the trench portion (not shown) are established as a function of the dimensions of shoulders 34b. To that end, an etch selectivity layer 40, shown in Fig. 6, is disposed adjacent to patterned imprinting layer 34 after solidified bi-level protrusions 34e have been formed. Substrate 31, patterned imprinting layer 34 and etch selectivity layer 40 define a multi-layered structure 38.

[0040] Referring to Fig. 6, etch selectivity layer 40 may be applied using any known process, including chemical vapor deposition (CVD), physical vapor deposition (PVD), sputtering and spin-on techniques. Spin-on deposition of etch selectivity layer 40 may be beneficial when recording patterns having numerous features per unit area, i.e., a dense featured pattern. In the present example, etch selectivity layer 40 is deposited employing imprint lithography processes, such as those discussed above with respect to depositing patterned imprinting layer 34. To that end, etch selectivity layer 40 may be formed from a polymerizable material similar to that

described above with respect to Figs. 3 and 4, excepting that the material from which etch selectivity layer 40 is formed includes silicon, i.e., is a silicon-containing polymerizable material. An exemplary compound for use as etch selectivity layer 40 is formed approximately 48% by weight of a silyl acrylate sold under product code SIA 0210 and available from Gelest, Inc. of Morrisville, Pennsylvania; approximately 24% by weight of a Butyl Acrylate monomer available from Sigma-Aldrich Corporation of St. Louis, Missouri; approximately 24% by weight of a silyl dimethacrylate sold under product code SIB 1402, from Gelest, Inc. of Morrisville, Pennsylvania; and approximately 4% by weight of a free radical generator sold under the tradename Darocur® and available from Ciba of Tarrytown, New York. Etch selectivity layer 40 includes first and second opposed sides. First side 40b faces patterned imprinting layer 34 and has a profile complementary to the profile of the patterned imprinting layer 34. The second side faces away from patterned imprinting layer 34 forming normalization surface 40a. Normalization surface 40a is provided with a substantially normalized profile by ensuring that the distances between an apex surface 34f of each of projections 34a and normalization surface 40a are substantially the same and that the distance between each of shoulders 34b and normalization surface 40a is substantially the same and the distance between a nadir surface 34g of each of sub-portions 34c, shown in Fig. 5, and normalization surface 40a is the same.

[0041] One manner in which to provide normalization surface 40a with a normalized profile involves use of a mold 127 having a smooth surface, i.e., featureless surface 127a, coming into contact with etch selectivity

layer 40. As mentioned above, this may be accomplished by moving imprint head 18, shown in Fig. 1, along the Z-axis, moving motion stage 20 along the Z-axis, or both. Thereafter, mold 127 is separated from etch selectivity layer 40 and actinic radiation impinges upon etch selectivity layer 40 to polymerize and, therefore, to solidify the same.

[0042] Referring to Figs. 6 and 7, a blanket etch is employed to remove portions of etch selectivity layer 40 to provide multi-layered structure 38 with a crown surface 38a. An exemplary etch process employs a CF_4 plasma etch where a predominant portion of the etch gases consists of CF_4. An exemplary etch chemistry is discussed by Johnson et al. in ADVANCES IN STEP AND FLASH IMPRINT LITHOGRAPHY, in a white paper distributed at the SPIE Microlithography conference held in Santa Clara, California from February 23-February 28, 2003. Crown surface 38a is defined by an exposed apex surface 30f of each of projections 34a and upper surfaces of portions 40c that remain on etch selectivity layer 40 after the blanket etch.

[0043] Referring to Figs. 7 and 8, crown surface 38a is subjected to an anisotropic etch. The etch chemistry of the anisotropic etch is selected to maximize etching of projections 34a and the segments of patterned imprinting layer 34, shown in Fig. 6, in superimposition therewith, while minimizing etching of the portions 40c. In the present example, advantage was taken of the distinction of the silicon content between the patterned imprinting layer 34 and the etch selectivity layer 40. Specifically, employing a plasma etch in which oxygen is the predominant gas, it was determined that an in-situ hardened mask 42 would be created in the regions of

portions 40c proximate to crown surface 38a. An exemplary etch chemistry is discussed by Johnson et al. in ADVANCES IN STEP AND FLASH IMPRINT LITHOGRAPHY, in a white paper distributed at the SPIE Microlithography conference held in Santa Clara, California from February 23-February 28, 2003. This results from the interaction of the silicon-containing polymerizable material with the oxygen-based plasma. As a result of the hardened mask 42 and the anisotropicity of the etch process, regions 44 on substrate 31 in superimposition with projections 34a are exposed. In the present example, regions 44 are exposed areas of etch barrier 31b, shown in Fig. 2. The width U of regions 44 is optimally equal to width W_2, shown in Fig. 2.

[0044] Referring to Fig. 8, after exposure of regions 44, a fluorine-based plasma etch, such as a type employing CF_4 gases discussed by Johnson et al. in ADVANCES IN STEP AND FLASH IMPRINT LITHOGRAPHY, in a white paper distributed at the SPIE Microlithography conference held in Santa Clara, California from February 23-February 28, 2003, is employed to remove regions of multi-layered structure 38 in superimposition with hardened mask 42, shown in Fig. 7, to expose regions 45a and 45b, shown in Fig. 9, each of which has a width U', which is optimally equal to W_2. Regions 45a and 45b define a groove portion 46 and a throughway 48 extending from regions 45a and 45b to region 44 defining a via portion. The groove portion 46 defines a trench portion, and throughway 48 defines a via portion. A subsequent etch process is employed to remove remaining portions of layers 34 and 40. Thereafter, the via portion and the trench portion may be concurrently filled with a conductive material, such as aluminum, copper, tungsten, titanium, ti-tungsten or a combination

thereof and the like, to form a contact 50 and a conductive line 52, shown in Fig. 10.

[0045] Referring to Figs. 2, 7 and 8, the advantages of this process are manifold. For example, the relative etch rate between portions 40c and exposed apex surface 30f may be in a range of about 1.5:1 to about 100:1 due to the presence of the hardened mask 42. As a result, self-aligned vias and trenches may be formed in substrate 31 while precisely controlling the dimensions thereof. This reduces transfer distortions of the pattern on the inverse shape of bi-level protrusions 34e, shown in Fig. 5, into substrate 31.

[0046] Referring to Figs. 5 and 9, additionally, the control of dimensional widths U and U' becomes relatively independent of residual thickness t_3. The rate at which the polymerizable fluid fills the pattern on patterned mold 27 is inversely proportional to the cube of residual thickness t_3. As a result, residual thickness t_3 may be selected to maximize throughput without substantially increasing transfer distortions. Finally, forming patterned imprinting layer 34 from a substantially silicon-free polymerizable fluid eases the cleaning process of patterned mold 27, especially considering that patterned mold 27 is often formed from fused silica.

[0047] Referring to Figs. 2 and 11, an additional advantage with the present invention is that the need to use etch barrier layers 31d and 31b may be abrogated. As is well known, by avoiding the use of etch barrier layers 31d and 31b, the overall dielectric constant of substrate 31 may be reduced, thereby making this process suitable for fabricating vias and trenches in furtherance of the fabrication of high speed integrated circuits. To that end, etch conditions are established so that the material

from which etch selectivity layer, shown in regions 140c, and dielectric layer 131c are established to be substantially inert to the etch chemistry employed to remove material from which patterned imprinting layer 34 is formed. In the present example, the material from which regions 140c and dielectric layer 131c are formed is relatively inert to an oxygen plasma etch.

[0048] Referring to Figs. 11 and 12, crown surface 138a, formed in a manner discussed above with respect to crown surface 38a in Fig. 7, is subjected to an oxygen plasma etch. As a result of the aforementioned etch selectivity differences, apex surface 130f, is removed along with the entire extent of projection 134a, shown as m_1, along with all material superimposed thereby in imprinting material layer 134. In this manner, a first segment 148a of via portion is formed.

[0049] A subsequent blanket plasma etch is employed using a fluorine-based chemistry, as discussed above. The blanket etch removes hardened mask 142 and regions 140c, shown in Fig. 11, to expose shoulders 134b, shown in Fig. 13. Concurrently with exposing shoulders 134b, a second segment 148b of via portion (not shown) is formed by removal of material of dielectric layer 131c, shown as m_2.

[0050] Referring to Figs. 13 and 14, an anisotropic oxygen-based plasma etch is employed to remove hardened shoulders 134b, as well as material of imprinting material layer 134 in superimposition therewith, to expose regions 145a and 145b of dielectric layer 131c, thereby forming a trench portion 146. Concurrently with exposing regions 145a and 145b, a third segment 148c of the via portion is formed by removal of material of dielectric layer 131c, shown as m_3. The combined length of via segments 148a, 148b and 148c defines a via portion

148 that is aligned with trench portion 146. In this manner, a self-aligned via and trench may be fabricated.

[0051] Referring to Figs. 5 and 15, although the present invention has been discussed with respect to formation of a self-aligned via and trench, the present invention may be employed to form various multi-tiered structures. For example, as shown in Fig. 5, associated with each protrusion 34e may be a pair of spaced-apart shoulders 34b equally spaced from apex surface 34f at height h_1 and flanking projection 34a. Alternatively, protrusion 134e may include a single shoulder 134b concentric about apex surface 134f, shown in Fig. 16.

[0052] Referring to Fig. 17, additionally, each protrusion 234e may include a plurality of shoulders 234a, 234b, 234c and 234d, spaced-apart from apex surface 234f at differing heights h_1, h_2, h_3 and h_4, respectively. Although four sets of shoulders 234a, 234b, 234c and 234d are shown, in reality any number may be included from 0 to n, where "n" is an integer number. To that end, a mold (not shown) would have one or more recesses formed into a surface thereof that would be complementary to the shape of protrusion 234e. Further, shoulders 234a, 234b, 234c and 234d may flank apex surface 234f, as shown in Fig. 18. Alternatively, shoulders 234a, 234b, 234c and 234d may be concentrically disposed about apex surface 234f, as shown in Fig. 19. Employing protrusion 234e, a substrate 231 may be formed to have a recess complementary to the shape of protrusion 234e, shown as 250 in Fig. 20. Although substrate 231 is shown as being from a homogenous material, e.g., silicon, any number of layers (not shown) of material may be included on substrate 231 and recess 250 may be formed in one or more of the aforementioned layers and/or substrate 231.

Further, the layers may consist of any material suitable for semiconductor processing.

[0053] Referring to Figs. 2 and 21, the foregoing has been discussed with respect to formation of recesses on substrate 31 employing mold 27 having a plurality of recesses formed therein. However, the same processes mentioned above may be employed to form islands 335 on substrate 331. To that end, mold 327, shown in Fig. 22, includes one or more protrusions 328 extending from a surface 328a having a projection 328b and a shoulder 328c spaced-apart from projection 328b between surface 328a and projection 328b. A layer of imprinting material is disposed on substrate 331 and spread to form a patterned layer 334 as discussed above. In this manner, patterned layer 334 includes a pattern complementary to the pattern on mold 327. In the present example, this results in one or more recesses 334a being formed in patterned layer 334.

[0054] Referring to Figs. 22 and 23, thereafter an etch selectivity layer 340 is disposed upon patterned layer 334 and a crown surface 340a to form a multi-layered structure 338 formed as discussed above. In this fashion, the only portions of etch selectivity layer 340 remaining after formation of crown surface 340a fills recesses 334a. Crown surface 340a is exposed to an oxygen etch chemistry that is highly selective in portions of patterned layer 334 not superimposed by recesses 334a and is removed to expose regions 344 of substrate 331, shown in Fig. 24. This is achieved, in part, due to a hardened mask 342 that is formed by the silicon present in the remaining portions of etch selectivity layer 340 when exposed to a plasma etch using

a chemistry that is predominantly composed of oxygen gases, as discussed above.

[0055] Referring to Figs. 21 and 24, after exposure of regions 344, a fluorine-based plasma etch, such as a type discussed above, is employed to remove regions of multi-layered structure 338, shown in Fig. 23, in superimposition with hardened mask 342 to expose regions 345. Specifically, the etch rate differential between regions 344 and hardened mask 342 results in the formation of islands 335. It should be understood, however, that any of the stepped features mentioned above may be formed in this manner, depending upon the pattern on mold 327, shown in Fig. 22. Further, although substrate 331 is shown as being from a homogenous material, e.g., silicon, any number of layers (not shown) of material may be included on substrate 331 and islands 335 may be formed in one or more of the aforementioned layers and/or substrate 331. Further, the layers may consist of any material suitable for semiconductor processing.

[0056] Referring to both Figs. 1 and 2, an exemplary radiation source 22 may produce ultraviolet radiation. Other radiation sources may be employed, such as thermal, electromagnetic and the like. The selection of radiation employed to initiate the polymerization of the material in patterned imprinting layer 34 is known to one skilled in the art and typically depends on the specific application which is desired. Radiation source 22 is located so that patterned mold 27 is positioned between radiation source 22 and substrate 31. As a result, substrate 31 and/or patterned mold 27 may be fabricated from materials that allow the same to be substantially transparent to the radiation produced by radiation source

22. Exemplary materials include, but are not limited to, fused-silica, quartz, silicon, organic polymers, siloxane polymers, borosilicate glass, fluorocarbon polymers, metal, and combinations of the above.

[0057] It may be desired to manufacture components of system 10 from materials that are thermally stable, e.g., have a thermal expansion coefficient of less than about 10 ppm/degree Centigrade at about room temperature (e.g. 25 degrees Centigrade). In some embodiments, the material of construction may have a thermal expansion coefficient of less than about 10 ppm/degree Centigrade, or less than 1 ppm/degree Centigrade. To that end, bridge supports 12, bridge 14, and/or stage support 16 may be fabricated from one or more of the following materials silicon carbide, iron alloys available under the trade-name INVAR®, or trade-name SUPER INVAR™, ceramics including, but not limited to, ZERODUR® ceramic. Additionally, table 24 may be constructed to isolate the remaining components of system 10 from vibrations in the surrounding environment. An exemplary table 24 is available from Newport Corporation of Irvine, California.

[0058] Referring to Figs. 1, 2 and 3, the characteristics of material 36a are important to efficiently pattern substrate 31 in light of the unique deposition process employed. As mentioned above, material 36a is deposited on substrate 31 as a plurality of discrete and spaced-apart beads 36. The combined volume of beads 36 is such that the material 36a is distributed appropriately over an area of surface 32 where patterned imprinting layer 34 is to be formed. As a result, patterned imprinting layer 34 is spread and patterned concurrently with the pattern being subsequently set by exposure to radiation, such as ultraviolet radiation. As a result of the deposition

process it is desired that material 36a have certain characteristics to facilitate rapid and even spreading of material 36a in beads 36 over surface 32 so that all thicknesses t_1 are substantially uniform and all residual thicknesses t_2 are substantially uniform.

[0059] Referring to Figs. 3 and 25, employing the compositions described above in material 36a, to facilitate imprint lithography a primer layer 456 is included on substrate 431. Primer layer 456 functions, *inter alia*, to provide a standard interface with patterned imprinting layer 434, thereby reducing the need to customize each process to the material from which substrate 431 is formed. In addition, primer layer 456 may be formed from an organic material with the same etch characteristics as patterned imprinting layer 434. Primer layer 456 is fabricated in such a manner so as to possess a continuous, smooth, relatively defect-free surface that may exhibit excellent adhesion to patterned imprinting layer 434.

[0060] Additionally, to ensure that patterned imprinting layer 434 does not adhere to patterned mold 27, surface 27a may be treated with a low surface energy coating 458. As a result, patterned imprinting layer 434 is located between primer layer 456 and coating 458 upon contact of patterned mold 27 with substrate 431. Coating 458 may be applied using any known process. For example, processing techniques may include chemical vapor deposition method, physical vapor deposition, atomic layer deposition or various other techniques, brazing and the like. In a similar fashion a low surface energy coating may be applied to mold 127, shown in Fig. 6. Alternatively, release properties of either patterned imprinting layer 34 or etch selectivity layer 40 may be improved by

including in the material from which the same is fabricated a compound having low surface energy, referred to as a surfactant. The compound is caused to migrate to a surface of layer therewith to interface with molds 27 and/or 127, shown in Figs. 2 and 6, respectively, using known techniques. Typically, the surfactant has a surface energy associated therewith that is lower than a surface energy of the polymerizable material in the layer. An exemplary material and process by which to form the aforementioned surfactant is discussed by Bender et al. in MULTIPLE IMPRINTING IN UV-BASED NANOIMPRINT LITHOGRAPHY: RELATED MATERIAL ISSUES, Microelectronic Engineering pp. 61-62 (2002). The low surface energy of the surfactant provides the desired release properties to reduce adherence of either imprinting layer 34 or etch selectivity layer 40 to molds 27 and/or 127, shown in Figs. 2 and 6, respectively. It should be understood that the surfactant may be used in conjunction with, or in lieu of, low surface energy coatings 458, shown in Fig. 25.

[0061] The embodiments of the present invention described above are exemplary. Many changes and modifications may be made to the disclosure recited above, while remaining within the scope of the invention. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.

WHAT IS CLAIMED IS:

1. A method of forming a stepped-structure on a substrate, said method comprising:

forming, on said substrate, a multi-tiered structure having a shape; and

transferring an inverse of said shape into said substrate.

2. The method as recited in claim 1 wherein transferring further includes transferring said inverse of said shape into said substrate to form a via portion and a trench portion, with dimensions of said via portion being established as a function of dimensions of a first sub-portion of said multi-tiered structure and dimensions of said trench portion being established as a function of dimensions of a second sub-portion of said multi-tiered structure.

3. The method as recited in claim 1 wherein transferring further includes covering, with an etch selectivity layer, said multi-tiered structure, with said substrate, said etch selectivity layer and said multi-tiered structure defining a multi-layered structure and removing portions of said multi-layered structure to expose regions of said substrate in superimposition with a first sub-portion of said multi-tiered structure while forming a hard mask in areas of said etch selectivity layer in superimposition with a second sup-portion of said multi-tiered structure.

4. The method as recited in claim 1 wherein transferring further includes covering, with an etch selectivity layer, said multi-tiered structure, and said etch selectivity layer, said substrate, said multi-tiered

structure defining a multi-layered structure and subjecting said multi-layered structure to etch processes that sequentially remove first and second batches of material from said multi-layered structure, with said first batch of material corresponding to a first sub-portion of said multi-tiered structure, first portions of said etch selectivity layer in superimposition therewith and portions of said multi-tiered structure and said substrate superimposed by a first sub-portion of said multi-tiered structure and said second batch of material corresponding to said shoulders, second portions of said etch selectivity layer in superimposition therewith and said second portions of said multi-tiered structure and said substrate superimposed by said shoulders.

5. The method as recited in claim 1 wherein forming further includes depositing a polymerizable fluid composition on said substrate and contacting said composition with a mold having a relief structure including a shape complementary to said shape of said multi-tiered structure and exposing said composition to actinic radiation to polymerize said composition.

6. The method as recited in claim 1 wherein forming further includes forming said multi-tiered structure from an organic polymerizable material substantially free of silicon and covering further includes forming said etch selectivity layer from a silicon-containing material.

7. The method as recited in claim 1 wherein forming further includes forming said multi-tiered structure from a material having a polymerizable compound and a surfactant having a surface energy that is less than a surface energy of said polymerizable compound.

8. The method as recited in claim 1 wherein covering further includes forming said etch selectivity layer from a material having a polymerizable compound and a surfactant having a surface energy that is lower than a surface energy of said polymerizable compound.

9. The method as recited in claim 1 wherein covering further includes forming said etch selectivity layer by disposing, on said multi-tiered structure, a polymerizable fluid composition and contacting said polymerizable fluid composition with a mold having a substantially smooth surface and subjecting said polymerizable fluid composition to conditions to polymerize said polymerizable fluid composition.

10. The method as recited in claim 1 wherein covering further includes disposing said etch selectivity layer by spin-coating a silicon-containing material on said multi-tiered structure.

11. The method as recited in claim 1 further including forming, on said substrate, an etch stop layer positioned between said substrate and said multi-tiered structure.

12. The method as recited in claim 1 further including depositing in said via portion and said trench portion, a conductive material.

13. The method as recited in claim 1 wherein said multi-tiered structure includes a stepped recess.

14. The method as recited in claim 13 further including forming said substrate from a wafer and a film layer and wherein transferring further includes

transferring said inverse of said shape into said film layer.

15. The method as recited in claim 13 further including forming said substrate from said wafer and said film layer and wherein transferring further includes transferring said inverse of said shape into said wafer.

16. The method as recited in claim 1 wherein said multi-tiered structure includes a bi-level protrusion including a projection and shoulders, with said projection having an apex surface and said shoulders being spaced-apart from said apex surface and said substrate.

17. The method as recited in claim 16 further including forming said substrate from said wafer and said film layer and wherein transferring further includes transferring said inverse of said shape into said film layer.

18. The method as recited in claim 16 further including forming said substrate from said wafer and said film layer and wherein transferring further includes transferring said inverse of said shape into said wafer.

19. A method of forming a stepped-structure on a substrate, said method comprising:

forming, on said substrate, a multi-tiered structure;

covering, with an etch selectivity layer, said multi-tiered structure, with said substrate, said etch selectivity layer and said multi-tiered structure defining a multi-layered structure;

defining regions of said substrate to be etched as a function of portions of multi-tiered structure exposed by removal of said etch selectivity layer.

20. The method as recited in claim 19 wherein forming further includes forming said multi-tiered structure with a projection and shoulders and defining said regions further includes concurrently removing portions of said multi-layered structure to form a via portion in a region of said substrate in superimposition with a projection while forming a hard mask in areas of said etch selectivity layer in superimposition with said shoulders by exposing said multi-layered structure to a plasma etch.

21. The method as recited in claim 19 wherein forming further includes depositing a polymerizable fluid composition on said substrate and contacting said composition with a mold having a relief structure including a shape complementary to a shape of said multi-tiered structure and exposing said composition to actinic radiation to polymerize said composition.

22. The method as recited in claim 19 wherein forming further includes forming said multi-tiered structure from an organic polymerizable material substantially free of silicon and covering further includes forming said etch selectivity layer from a silicon-containing material.

23. The method as recited in claim 21 wherein covering further includes forming said etch selectivity layer by disposing, on said multi-tiered structure, said polymerizable fluid composition and contacting said

polymerizable fluid composition with a mold having a substantially smooth surface and subjecting said polymerizable fluid composition to conditions to polymerize said polymerizable fluid composition.

24. The method as recited in claim 21 wherein covering further includes disposing said etch selectivity layer by spin-coating said silicon-containing material on said multi-tiered structure.

25. The method as recited in claim 21 wherein forming further includes forming said multi-tiered structure from a material having a polymerizable compound and a surfactant having a surface energy that is less than a surface energy of said polymerizable compound.

26. The method as recited in claim 21 wherein covering further includes forming said etch selectivity layer from a material having a polymerizable compound and a surfactant having a surface energy that is lower than a surface energy of said polymerizable compound.

27. The method as recited in claim 19 wherein said multi-tiered structure includes a stepped recess having a shape.

28. The method as recited in claim 27 further including forming said substrate from a wafer and a film layer and transferring an inverse of said shape into said film layer.

29. The method as recited in claim 27 further including forming said substrate from said wafer and said film layer and wherein transferring further includes transferring said inverse of said shape into said wafer.

30. The method as recited in claim 19 wherein said multi-tiered structure includes a bi-level protrusion including a projection and shoulders, with said projection having an apex surface and said shoulders being spaced-apart from said apex surface and said substrate, said bi-level protrusion defining a shape.

31. The method as recited in claim 30 further including forming said substrate from said wafer and said film layer and wherein transferring further includes transferring said inverse of said shape into said film layer.

32. The method as recited in claim 31 further including forming said substrate from said wafer and said film layer and wherein transferring further includes transferring said inverse of said shape into said wafer.

33. A method of forming a stepped structure on a substrate, said method comprising:

forming a patterned layer on said substrate having a bi-level protrusion including a projection and shoulders, said projection having an apex surface with said shoulders being spaced-apart from said apex surface and said substrate;

covering said projection with an etch selectivity layer;

creating a crown surface by removing a portion of said etch selectivity layer to expose said apex surface, with remaining portions of said bi-level protrusion remaining covered by said etch selectivity layer;

removing said apex surface and material of said patterned layer in superimposition with said apex surface

while avoiding exposure of remaining portions of said bi-level protrusion;

removing areas of said etch selectivity layer in superimposition with said remaining portions of said bi-level protrusion to expose said shoulders; and

removing said shoulders and said patterned layer in superimposition therewith.

34. The method as recited in claim 33 wherein forming further includes depositing a polymerizable fluid composition on said substrate and contacting said composition with a mold having a relief structure including a shape complementary to a shape of said bi-level protrusion and exposing said composition to actinic radiation to polymerize said composition.

35. The method as recited in claim 33 wherein forming further includes forming said patterned layer from an organic polymerizable material substantially free of silicon and covering further includes forming said etch selectivity layer from a silicon-containing material.

36. The method as recited in claim 35 wherein removing said apex surface further includes subjecting said crown surface to an etch chemistry that is highly reactive with material from which said bi-level protrusion is formed and forms a hard mask in the region of said crown surface that comprises material from which said etch selectivity layer is formed.

37. The method as recited in claim 35 wherein covering further includes forming said etch selectivity layer by disposing, on said patterned layer, a polymerizable fluid composition and contacting said

polymerizable fluid composition with a mold having a substantially smooth surface and subjecting said polymerizable fluid composition to conditions to polymerize said polymerizable fluid composition.

38. The method as recited in claim 35 wherein covering further includes disposing said etch selectivity layer by spin-coating a silicon-containing material on said patterned layer.

39. The method as recited in claim 35 wherein forming further includes forming said patterned layer from a material having a polymerizable compound and a surfactant having a surface energy that is less than a surface energy of said polymerizable compound.

40. The method as recited in claim 35 wherein covering further includes forming said etch selectivity layer from a material having a polymerizable compound and a surfactant having a surface energy that is lower than a surface energy of said polymerizable compound.